IOP Impacts on Salinity in Everglades National Park

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1. Introduction

Here we report a series of salinity impact studies conducted by Everglades National Park (ENP) staff and consultants to assess the impact of Interim Structural and Operational Plan/Interim Operational Plan (ISOP/IOP) on salinity within and adjacent to ENP. Salinity may be affected by changes in upstream water management and directly impacts the function of estuarine systems, making it one of the most important water quality variables to be considered in the IOP review. A series of ISOP/IOP was started in November 1999. The ISOP/IOP is designed to influence the timing and allocation of surface water flowing into the Park across Tamiami Trail from the north and through the L-31W and C-111 canals from the east. The ISOP/IOP review weighs the impacts of these water management operations on salinity of the coastal mangroves and estuaries in ENP and adjacent areas.

The objectives of the salinity impact studies are (1) to investigate change in salinity as a result of IOP, (2) to test whether the change is statistically significant, and (3) to identify further monitoring and research needed to assess accurately the long-term impact of ISOP/IOP or its modification. The expectations from the Everglades restoration efforts, including Modified Water Deliveries and C-111 projects, in terms of salinity are to decrease the salinity concentration level and to reduce the occurrence of hyper-salinity conditions for the health of estuarine ecosystem.

To meet the above objectives, two independent studies have been completed: Smith (2003) analyzed ISOP/IOP impact using historical salinity data and a Before-After and Impact-Control (BACI) approach. Marshall (2003) developed salinity prediction models, based on a statistical approach. Marshall tested and used his models to investigate salinity change due to ISOP/IOP implementation based on long-term simulations. He simulated long-term salinity values based on the simulations of different operation conditions with the same hydro-meteorological condition. This method allows us to control for climate changes over a relatively long period and focus on conditions that are only the management change. The Table 1.1 compares main features of these two studies.

The next section presents summary statistics and the differences of average salinity values between the ISOP/IOP and Test 7I periods. Subsequent sections introduce briefly the methods, major results, and discussions and conclusions of the results.

Table 1.1. Comparison of two approaches for analyzing the salinity data in Florida Bay where site acronyms are defined on Table 2.1.

Item	BACI Approach by Smith (2003)	Model Simulation by Marshall (2003)
Approach	BACI	Statistical model (multiple linear regression model)
Number of Stations Analyzed	16 (MD, HC, LS, JB, BS, BN, TR, LM, TB, WB, NR, CW, TE, GI, BR)	8 (LM, LS, JB, TB, NR, WB, DK, BN)
Modeling Time Step	Monthly Seasonal, and Yearly	Daily
Control/Indep. Variable	Rainfall, Wind	Stage, Wind
Analyzed Data	Historical	Historical, Simulated

2. Summary Statistics of Observed Salinity Data

Smith (2003) computed yearly, seasonal, and monthly statistics of historical salinity data from ENP. Sixteen salinity-monitoring stations were selected that cover the potential area of ISOP/IOP impact and have relatively few missing data (Figure 2.1). These stations are located in the following four zones: a) Manatee Bay and Barns Sound (BSMB) with 1 station (MD); b) Northern Florida Bay Basins (NFBB) with 6 stations (HC, LS, JB, TR, LM, TB); c) Florida Bay Open Water (FBOW) with 3 stations (BN, WB, BS); and d) Gulf Estuaries (GE) with 6 stations (NR, CW, CN, TE, GI, BR). Blackwater Sound (BS) is located at intermediate position between zone b and c.

Data from Middle Key (MD) and Joe Bay (JB) are collected by the Park but maintained by the South Florida Water Management District, while data at the remaining 14 sites are collected and maintained under the Physical Monitoring Program at ENP. Salinity values from the most sites are collected hourly, while those at MD and JB are sampled at 15 minutes intervals.

Salinity data from November 1995 to October 2002 was used for this analysis. The data were partitioned into a “before” period (1995-1999) and an “after” period (2000-2002). Water management operations were under Test 7I during the “before” period and under ISOP/IOP during the “after” period. The data were analyzed annually (November through October) as well as seasonally. The dry season extends from November to May and the wet season extends from June to October.

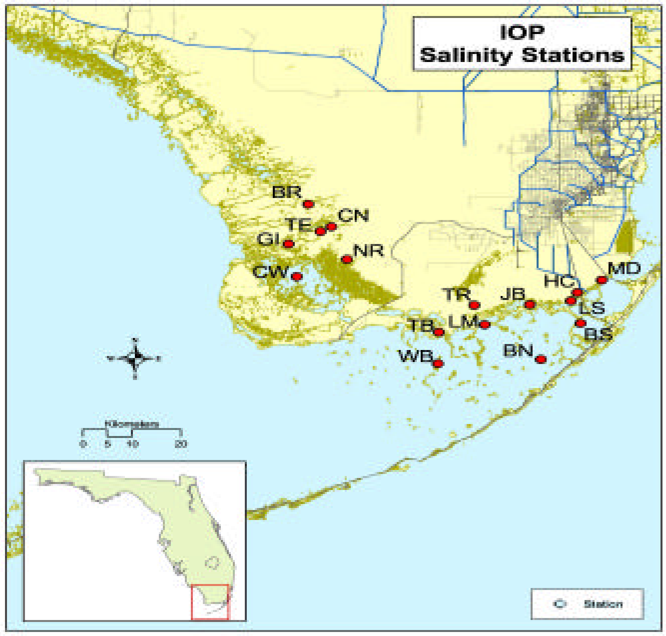

Figure 2.1. Salinity station locations and names.

Table 2.1 presents summary statistics at 16 selected salinity stations. Average salinity for stations in the Northern Florida Bay Basin area (14.6 ppt) is lower than that of the Florida Bay Open Water area (28.9 ppt). Average salinity in the Gulf Estuaries area (10.7 ppt) is the lowest among four zones. Of the six stations in the Northern Florida Bay Basin zone, Terrapin Bay has the highest mean and greatest variance, while Taylor River site shows the lowest mean. Average salinity during the dry season is higher in general than that of the wet season, but the opposite is true at Little Madeira and three open water stations. The higher salinity values during the wet season at these open water stations are partially explained by the delayed influence of runoff at these stations.

Salinity values at open water stations in Florida Bay (Figure 2.2) are often greater than standard seawater (35 ppt) when evaporation exceeds local rainfall and where movement of freshwater runoff and marine water is restricted by mud banks. The four upstream stations (BR, NR, CN, TR) have very low salinity values except during very dry periods and when storm winds drive saltier water upstream (e.g. October 1999). Time series show a distinct annual pattern that is somewhat different from the annual wet-dry rainfall pattern. At northern Florida Bay and Gulf Coast stations salinity values are highest at the end of the dry season and lowest during the middle of the wet season (Figure 2.3). However, the pattern is different at the open water stations where high salinity values are observed during the wet season and remain high longer than at stations located farther upstream. During the ISOP/IOP analysis period, salinity values were highest during 2001, a relatively dry year. Salinity values were generally higher during the ISOP/IOP period than during the Test 7I period (Figure 2.4).

Table 2.1. Summary statistics for salinity (ppt) from selected stations, where shaded value indicates that wet season salinity is higher than dry season salinity

Zone	Stations	Yearly Mean	Yearly SD	Dry Season Mean	Wet Season Mean	Monthly Min	Monthly Max
MBBS	Middle Key (MD)	25.6	1.6	26.4	24.5	17.1	41.6
NFBB	Highway Creek (HC)	11.5	3.3	14.8	6.7	0.3	33.7
	Long Sound (LS)	15.4	2.9	17.3	12.7	3.1	33.1
	Joe Bay (JB)	12.2	3.6	13.5	10.5	0.8	35.4
	Talyor River (TR)	6.2	3.5	6.7	5.9	0.2	36.0
	Little Medeira (LM)	19.6	3.7	19.1	20.5	8.1	37.7
	Terrapin Bay (TB)	22.7	5.8	23.0	22.4	3.8	47.8
FBOW	Blackwater Sound (BS)	25.5	2.3	24.9	26.2	14.9	35.5
	Butternut Key (BN)	27.5	3.2	25.0	31.0	16.3	37.5
	Whipray Basin (WB)	33.5	3.7	32.2	35.7	22.1	47.4
GE	Broad River (BR)	3.3	2.5	4.2	2.2	0.1	23.9
	Canepatch (CN)	1.3	1.2	1.8	0.7	0.0	14.7
	Tarpon Bay East (TE)	3.0	2.0	4.1	2.0	0.2	18.8
	Gunboat Island (GI)	11.0	2.7	13.7	7.9	1.1	28.2
	North River (NR)	6.4	2.8	8.1	4.8	0.2	28.5
	Clearwater Pass (CW)	16.4	2.7	18.2	15.0	3.2	34.5
Average or gloval max/min		15.1	3.0	15.8	14.3	0.0	47.8

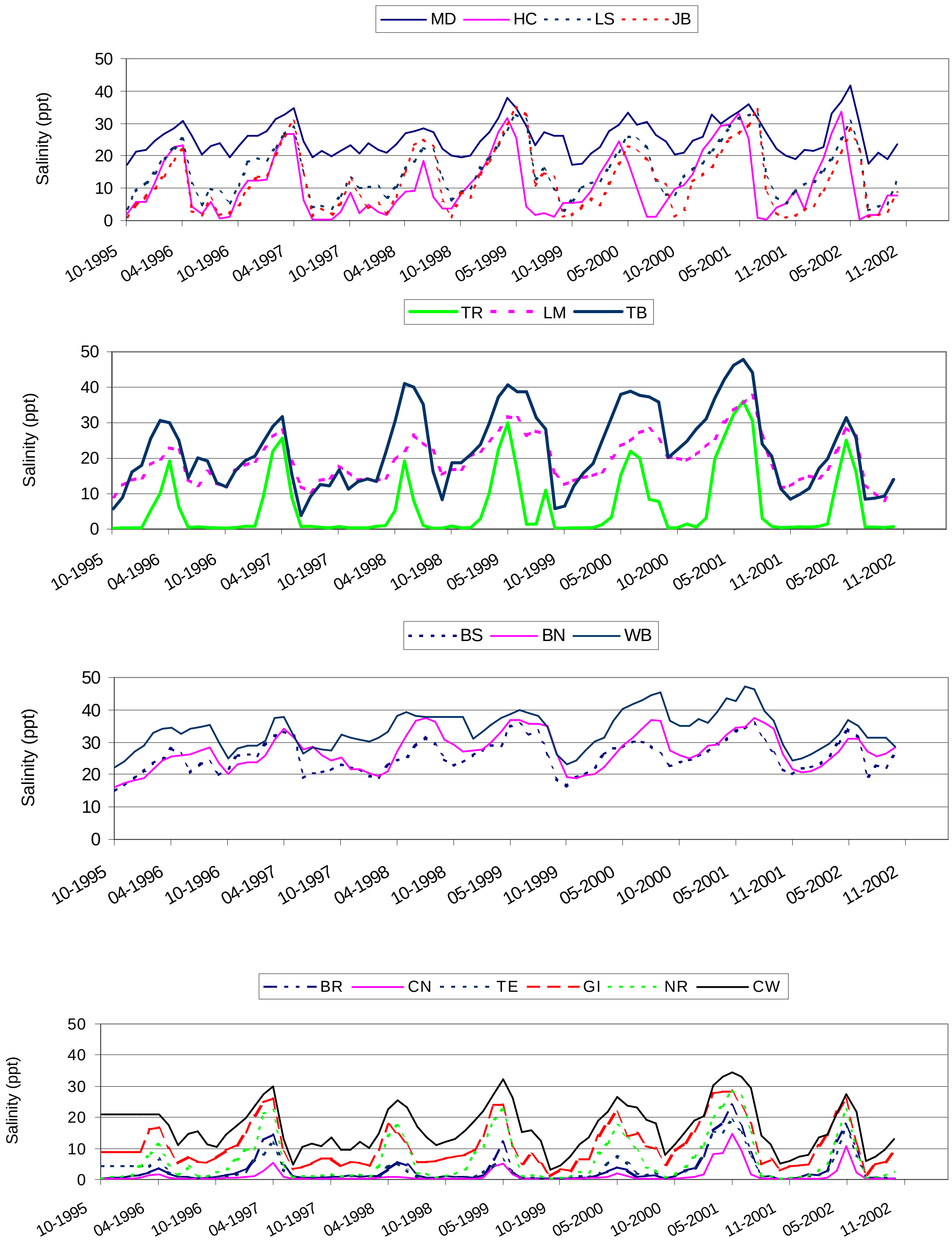

Figure 2.2. Time series plots of monthly salinity values in Florida Bay.

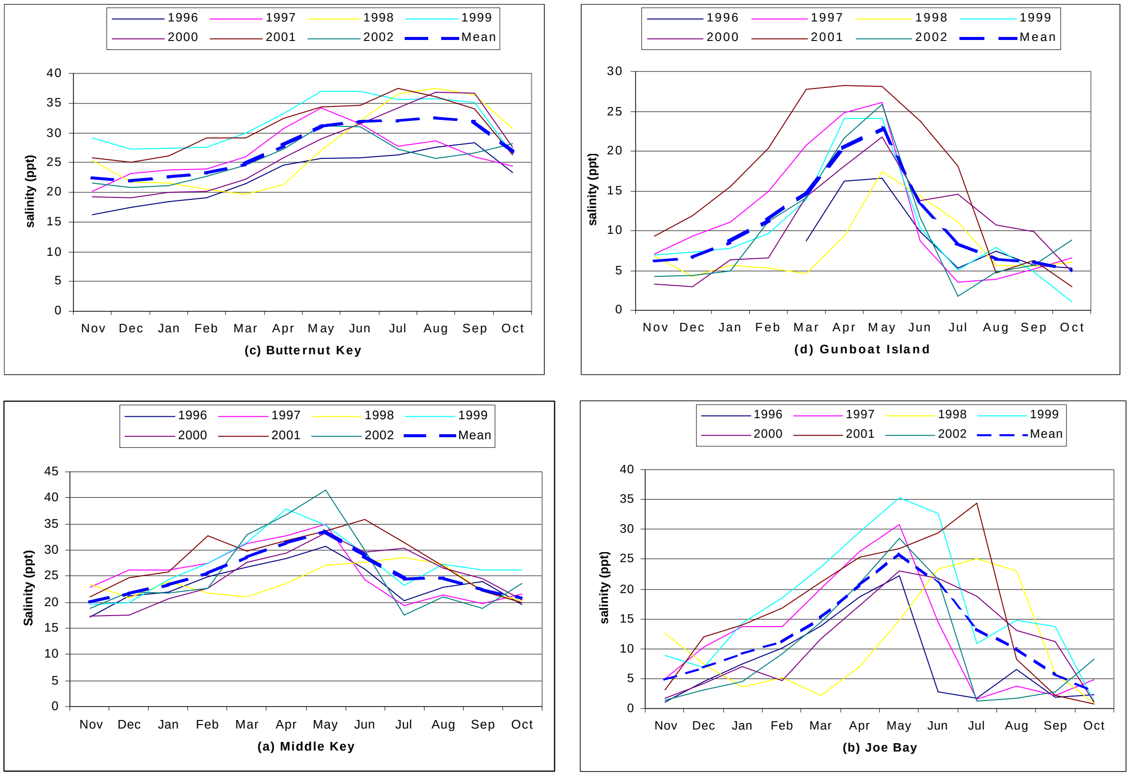

Figure 2.3. Monthly variations of salinity values from four selected stations.

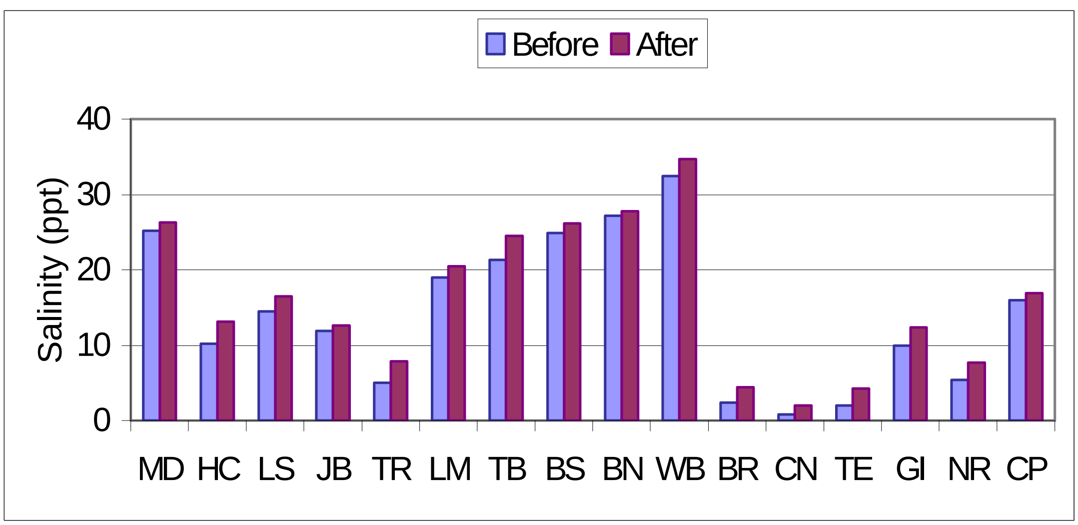

Figure 2.4. Comparison between “before” and “after” salinity values at each site.

3. Salinity Impact Analysis Based on a BACI Approach

3.1 Method

Smith (2003) analyzed ISOP/IOP salinity impacts in ENP estuaries using historical salinity data measured at 16 stations (Figure 2.1) from November 1995 through October 2002. A before-after (BA) design was used to look for differences in salinity and flow between the Test 7I period (1996-1999) and the ISOP/IOP period (2000-2002). A BACI design with controls for rainfall and wind was then used to detect changes likely to be the result of water management actions.

Salinity data collection at some stations started after the beginning of the study period and gaps of days to months occurred in several time series. Periods with excessive missing data were not used in the analysis and only results for complete time series (7 years, seasons, or months) are reported. Changes in salinity values for each of 16 salinity stations and mean flow at 4 locations were tested. The tests were done at annual, dry season, wet season and monthly mean values.

Discharges measured at Taylor Slough Bridge, S-18C, and S-197 are used to quantify runoff to northern Florida Bay and Barns Sound. Discharge through S-18C minus discharge through S-197 is hereafter referred to as C-111 flow. Wind speed and direction were recorded at the ten-meter Joe Bay tower in north Florida Bay. This study used rainfall measurements spatially averaged from 25 stations located in and around the ENP area (Ahn 2003).

Rainfall and lagged rainfall were used as control variables in BACI tests of mean annual and seasonal salinity data. Monthly tests used wind velocity and direction, converted to vector components, as control variables. Salinity, discharge, and rainfall were log-transformed to ensure normality and to provide input values within the same order of magnitude. Leven’s test was used to assess homogeneity of variance for a simple one-way analysis of variance test with before and after values. Autocorrelation is assumed to be minimal for monthly salinity and flow series. For example, salinity during January at station Joe Bay is assumed to be independent of the previous January salinity at Joe Bay. All statistical tests were preformed using the General Linear Model Procedure (SAS 1999).

3.2 Results

Tables 3.1 and 3.2 summarize magnitude of change at each salinity and flow station. Stations are listed from east to west and upstream to downstream in the table. Figure 3.1 shows the spatial pattern of observed differences, direction of change, and significance levels for the BACI analysis. Salinity stations are shown as round dots and flow stations as squares.

Annual and seasonal flows into wetlands upstream of Florida Bay (Taylor Slough and C-111) were greater during ISOP/IOP operations than during Test 7I operations. However, less water was released to Manatee Bay and Barnes Sound through structure S-197. Dry season changes were significant on the BA test at the 15% significance level but were not significant on the BACI test. Monthly wet season and early dry season (November-January) flows at Taylor Slough Bridge and S-18C were higher under ISOP/IOP operations than under Test 7I operations. Late dry season (February- June) monthly flows were reduced under IOP. January and July increased flows were significant at the 5-10% level using the BA test but were not significant on the BACI test. The only significant differences in flow found using the BACI model occurred during September and October.

Table 3.1. Yearly and seasonal salinity (ppt) and Flow (cfs) Changes from Test 7I to ISOP/IOP with Results of BA and BACI Significance Test.

Salinity Station	Abbr.		Year		Dry		Wet
Middle Key	MD		0.6	*	0.5		
Highway Creek	HC		1.7		1.5		2.0
Long Sound	LS		1.2		0.9		1.6
Joe Bay	JB		0.4		-0.2		
Blackwater Sound	BS		0.7	*	0.5		1.1
Butternut Key	BN		0.3		0.1		0.6
Taylor River	TR		1.6		0.4		3.2
Little Madiera	LM		0.9		0.5		1.3
Terrapin Bay	TB				0.8		3.2
Whipray Basin	WB		1.2				
North River	NR		1.3		0.9		
Clearwater Pass	CW						1.1
Cane Patch	CN		0.5		-0.7	*	1.1
Tarpon Bay East	TE					*	1.0
Gunboat Island	GI						1.6
Broad River	BR				1.3		
Lower Broad River	BD						2.0

Positive changes in salinity are shown in red and negative changes are shown in blue.

Flow Station	Abbr.		Year		Dry		Wet
Taylor Slough Bridge	TSB		13	*	12		14
C111 (S18C-S197)	C111		37	*	20		61
S18C	S18C		7	*	4		10
S197	S197		-31	*	-16		-51

Positive changes in flow are shown in blue and negative changes are shown in red.

BA		5%		10%		15%		20%	BACI		5%		10%		15%		20%	Hov	*	5%

Table 3.2. Monthly salinity (ppt) and Flow (cfs) Changes from Test 7I to ISOP/IOP with Results of BA and BACI Significance Test

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
MD	-1.0	-0.4	* -0.8	0.3	1.4	1.2	2.5	2.8	2.1	0.1	-0.6	
HC		0.9	-0.5	2.4	2.5	2.5	3.8			-1.4		
LS	0.3	0.3	-0.3	0.5	1.1	1.8	2.1	4.4	4.9	-1.7	-1.3	1.7
JB	-2.8	-0.4	-0.7	-1.0	0.4		0.1				-0.3	0.6
BS	-0.3	-0.2	* -0.2	0.5	1.1	1.5	1.1	1.2		0.1	0.1	1.4
BN	-0.3	-0.5		0.7	0.6	0.6	0.3	0.4	0.8	0.3	0.6	0.7
TR	-0.1	0.2	* 0.0		0.7	0.4	2.4			1.7		0.1
LM	0.5	0.1	* 0.2	0.1	-0.2	1.2	1.8	2.9	3.5	1.7		
TB	-0.5			1.8	2.2	2.1	3.0	4.3			1.6	3.0
WB				0.6	0.6	1.1	1.5	3.2				
NR	-0.2	0.1				1.8	3.0	4.2	2.7	-0.1		
CW						1.1	1.8	3.3	3.4	-0.6	-0.2	-0.2
CN	-2.3	-1.2	-0.7	-0.6	1.4	1.1	1.8		3.4		-0.2	-0.2
TE							4.2	3.4	1.1	0.1	0.5	-0.1
GI						2.3	2.4	3.2	3.0	0.3	1.1	0.4
BR	-0.2				2.4	3.2	3.8	3.7	1.0			
BD							4.3	4.3	2.3	1.0	1.4	

Positive changes in salinity are shown in red and negative changes are shown in blue.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
TS	67	10	* 22	7	-11	-3	-8	-55	48	46	10	18
C111	132	53	* 43	-9	-40	-10	-42	-41	73	70	112	96
S18C	46	40	* 43	-9	-40	-10	-42	-124	97	85	-20	12
S197	-85	-14						-83	24	15	-132	-84

Positive changes in flow are shown in blue and negative changes are shown in red.

BA	5%	10%	15%	20%	BACI	5%	10%	15%	20%	Hov	*	5%

Annual (November through October) and seasonal mean salinity generally increased with the change from Test 7I to ISOP/IOP. However, the changes at most stations were not significant on BACI test - only the annual change at Canepatch and the wet season changes at Butternut and Canepatch were significant at the 15-20% level. Observed differences were small (e.g. Canepatch annual mean was 1.2 ppt higher) and only part of these differences were the result of water management.

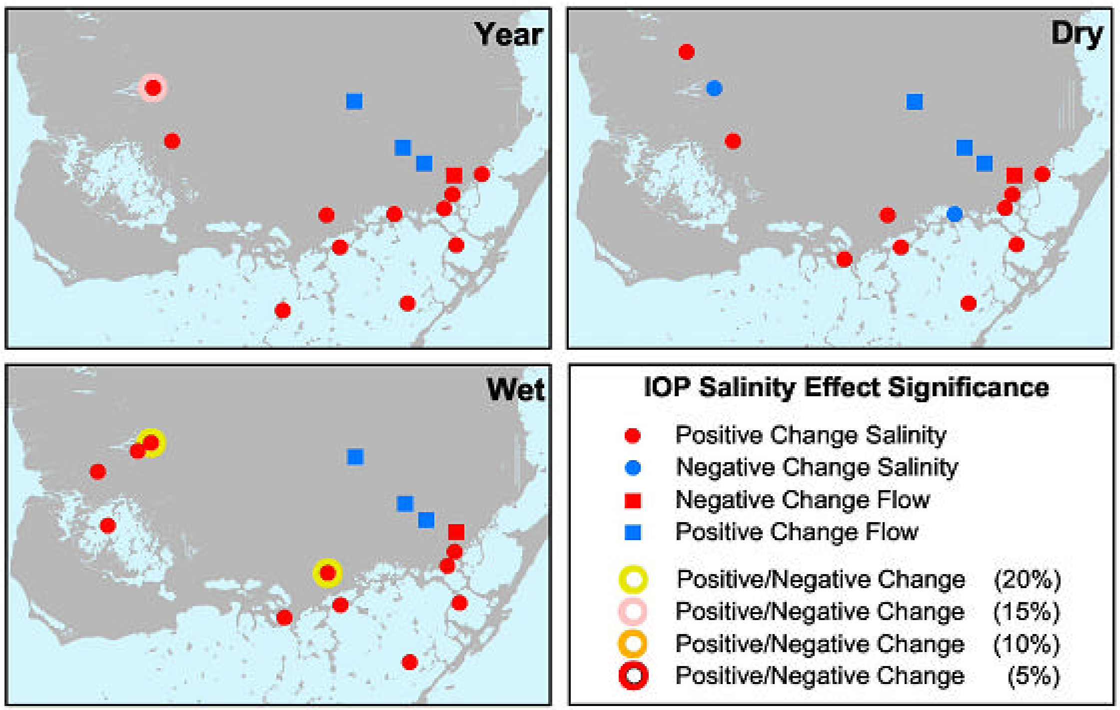

Figure 3.1. Change in salinity and flow during the ISOP/IOP period compared to the Test 7I period.

Monthly salinity at most stations was lower during ISOP/IOP from November through January but higher from February through July. These results were generally consistent with observed decreasing flow through Taylor Slough and the C111 Canal. March mean salinity at both Canepatch and Broad River was significantly higher (2.4 and 4.1 ppt respectively) in BACI test at the 10% level. These results are consistent with reduced flow in Shark Slough under IOP. March mean salinity at Highway Creek was also significantly higher during ISOP/IOP when tested with a BACI model. Increased salinity in Florida Bay or Gulf Coast estuaries as a result of changes in water management is generally counter to the goals of Everglades restoration.

3.3 Summary

Annual mean salinity was significantly higher (15% level) at the Canepatch monitoring station during the ISOP/IOP operational period when tested using a BACI model with rainfall and the previous wet season rainfall as control variables. Wet season mean salinity values at Canepatch and Taylor River were also higher significant at the 20%

significance level. Most other differences are small and only a portion is related to water management. March mean salinity values at Canepatch, Broad River, and Highway Creek were significantly higher during ISOP/IOP. These results are consistent with reduced flow in Shark Slough and the C111 Canal under ISOP/IOP. Increased salinity in Florida Bay or Gulf Coast estuaries as a result of changes in water management is generally counter to the goals of Everglades restoration.

The power of the BACI approach to detect change in salinity within South Florida estuaries could be increased when the BACI test is done at the smaller time intervals or with serial correlation terms in the BACI model. The power of the test to detect change could be improved when we use the larger sample size than the current one (n=7). Local wind, water level, and rainfall account for some salinity variation but the effect is probably greatest on time scales shorter than a month.

3.4 Recommendations

Improved understanding of evapotranspiration and rainfall in coastal mangrove and marsh areas and in open estuarine waters is needed to predict salinity in Florida Bay. NEXRAD information and data from our existing rain gauge network could be used to better define rainfall in these areas. Most of the rainfall data collected in the areas over the past 10 years is not currently being used effectively due to periods of missing data. No direct measurements of evapotranspiration have been made in the mangrove zone and evaporation from Whitewater Bay, Florida Bay and other open water bodies is not well documented.

Additional salinity measurements may be necessary to document salinity in coastal marsh and mangrove areas that are accessible only by airboat that is expensive. Salinity in these environments may be strongly affected by local rainfall and evaporation in addition to runoff from upstream and wind forcing from open water bodies downstream. Additional salinity monitoring should accompany biological monitoring (e.g. Crocodile, vegetation, and invertebrates), and if possible, should be related to data from long-term stations operated by the USGS/BRD Climate Change Project and Audubon Spoonbill Study.

Gaps in monitoring data need to be estimated so that time series methods can be used to develop an improved understanding of the relationships between salinity, local and regional rainfall, evapotranspiration, upstream discharge, wind, and water level. These relationships may be complex and may vary on different temporal and spatial scales. However, understanding them is essential if we are to parse management and climate signals.

4. Long-term Salinity Prediction Based on a Multivariate Regression Model

4.1 Method

Marshall (2003) developed and updated statistical models that simulate the daily salinity variation in parts of Florida Bay for use with the ISOP/IOP impact evaluation. These statistical models are based on a multivariate linear regression (MLR) approach. He developed eight MLR models: Five near shore salinity stations including Joe Bay, Little Madeira Bay, Terrapin Bay, North River, and Long Sound; and three open water stations including Whipray Basin, Butternut Key, and Duck Key (Figure 4.1). The period of data used for model development was March 24, 1995 through October 31, 2002. After the models were developed for each station, they were verified using data for the period March 24, 1994 through March 23, 1995.

The models were developed by the following two-step approach: First, the salinity models at near shore stations were developed using (a) 14 stage stations located in the park, (b) wind speed and direction measured at both Key West and Miami, and (c) sea level measured at Key West. Several hydraulic gradients are computed by inland surface water level data and used as additional independent variables. Second, the models at open bay stations were developed based on the salinity values measured at Little Madeira Bay and Terrapin Bay, as well as wind and tidal variables. Salinity values at Joe Bay and Long Sound were not significant for predicting the salinity values at these open water stations. With the addition of the hydraulic gradient parameters, there were 25 independent variables that, along with the five near shore salinity dependent variables, were subjected to a correlation analysis using an identification technique of seasonal time series model development. The models used both lagged and unlagged time-correlations. The significance of the correlation was determined by two standard deviations above or below the average correlation coefficient for all lags. Then, a modified stepwise regression technique was used to determine the significant variables in the five near shore location models. The level of significance for inclusion in the model was set at 0.999, a high threshold, and all terms in a model were tested to be sure that they were physically defensible. If not, they were eliminated from the list of candidate independent variables, and the model development procedure was re-run. This selective stepwise procedure produced relatively simple models with a high level of significance for all model parameters. This process yielded salinity models for all five near shore locations.

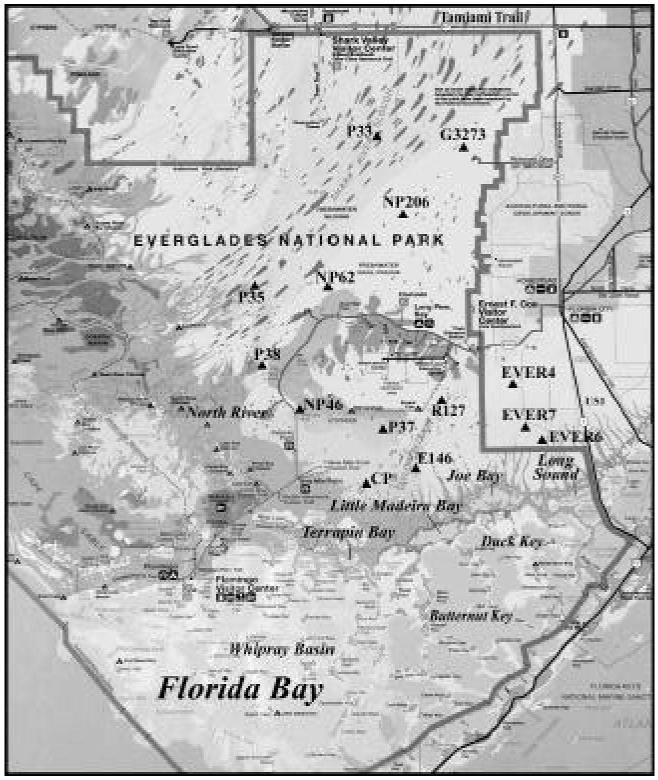

Figure 4.1. Map showing the location of salinity and water level stations used in the statistical salinity models.

4.2 Result of Model Simulations

Marshall (2003) presents the details of the salinity models. Plots of calibration and verification runs show that the models simulate salinity in these parts of Florida Bay reasonably well (Figure 4.2). To begin the ISOP/IOP evaluation, the five near shore models were used to make various runs using the South Florida Water Management Model (SFWMM) output for the input water levels, along with historic wind and sea level data. As part of the preliminary evaluation of uncertainty, it was found that the SFWMM model output for water level, when compared to observed data typically showed a systematic variation (bias) across the period of the data being compared (March 24, 1993 through December 31, 1995). To improve the accuracy of the simulations, the bias at each site was corrected by adding or subtracting the difference of the observed and modeled averages. The corrected SFWMM model output was then used with historical wind and tide to simulate salinity at the near shore stations. These modeled salinity values were then input to the Whipray Basin, Duck Key, and Butternut Key salinity models with wind and tide to simulate the salinity at the open water stations. The products are simulated daily salinity values for a 31-year period (1965-1995). Four scenarios were run using the MLR salinity models (Table 4.1).

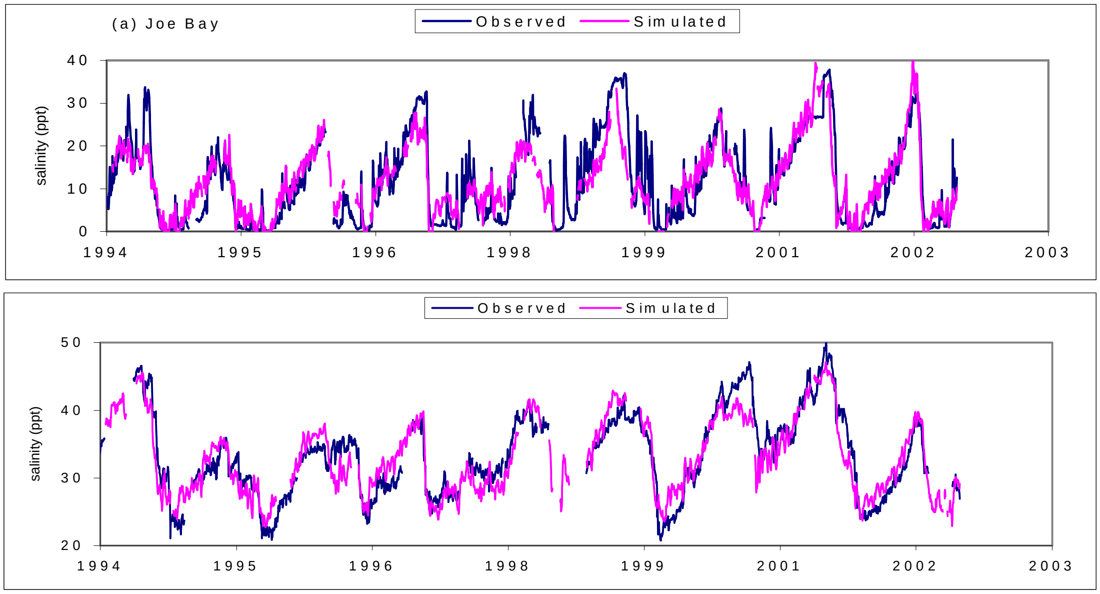

Figure 4.2. Comparison between observed (black) and simulated (grey) salinity values based on the statistical models at two arbitrary selected sites: (a) Joe Bay, and (b) Whipray Basin.

Table 4.1. Description of SFWMM scenarios used in the comparison of salinity projections (Nuttle 2003).

Scenario	Version	Description
BS1995	V4.4r13 95bm4	Regional hydrology under operation rules as they existed in 1995 based on climate inputs from 1965 through 1995.
IOP	V 4.4r13 Altr7r	Same as the above but under IOP operations
ISOP	V 4.4r13 Altcur	Regional hydrology under ISOP operations based on climate input from 1965 through 1995
Natural System Model	NSM V 4.5	Regional hydrology under pre-development conditions based on climate inputs from 1965 to 1995.

Table 4.2. Comparison of average daily salinity values (in psu) produced by statistical models for the indicated operational scenario simulated from SFWMM output and historic wind and sea level data, where * indicates an salinity decrease by IOP.

Run	Joe Bay	Little M.	Terrapin Bay	North River	Long Sound	Whipray Basin	Duck Key	Butter-nut Key
BS1995	13.08	20.76	27.19	7.35	19.93	34.89	26.26	28.01
IOP	12.48*	23.45	32.15	9.34	19.07*	37.17	28.26	29.77
ISOP	12.65	23.15	31.32	9.04	19.16	37.13	27.71	29.35
NSM	12.3	19.86	25.61	6.77	19.87	34.16	25.6	27.53

Table 2.2 compares the average salinity values from each scenario of the 31-year runs using the SFWMM model output. This analysis showed that, in general, the long-term average salinity is reduced for ISOP and IOP runs compared to the BS1995 scenario for Joe Bay and, to a limited extent at Long Sound. Average salinity increased for ISOP and IOP runs over BS1995 simulations for the remaining six stations. Even though there are noticeable differences between average salinity values of BS1995 and ISOP/IOP simulations, there is no statistically significant difference between the average values at the 80% (or higher) significance level. However when wet/dry season averages and monthly averages are compared utilizing 80% confidence intervals, some significant differences are noted (Table 5.3).

Table 4.3. Comparison of BS1995 and IOP runs based on wet and dry season averages for the 31-year simulations, where shaded site indicates that IOP change is significant at a 75% significant level and bold face indicates a salinity increase by IOP.

Site	Run	Dry Season				Wet Season			
		Mean	SD	80% Lower	80% Upper	Mean	SD	80% Lower	80% Upper
Joe Bay	BS1995	33.5	9.2	5.5	10.3	7.9	4.1	32.5	34.5
	IOP	35.0	8.9	4.9	9.5	**7.2**	4.6	33.8	36.2
Little M.	BS1995	22.0	5.8	20.5	23.5	17.9	5.8	16.4	19.4
	IOP	25.2	7.2	23.4	27.1	19.7	6.5	18.0	21.3
Terrapin Bay	BS1995	28.9	11.5	26.0	31.8	23.2	9.9	20.7	25.8
	IOP	35.0	13.7	31.5	38.5	26.4	11.1	23.5	29.2
North River	BS1995	10.8	9.3	8.4	13.2	3.2	5.8	1.8	4.7
	IOP	13.4	9.5	10.9	15.8	3.9	6.1	2.3	5.4
Long Sound	BS1995	24.6	11.9	21.6	27.7	13.4	8.0	11.3	15.4
	IOP	**24.1**	11.4	21.1	27.0	**12.2**	8.0	10.1	14.2
Whipray Basin	BS1995	35.8	5	34.5	37.1	23.4	5.9	21.9	24.9
	IOP	38.6	6	37.1	40.1	24.7	6.4	23.1	26.3
Duck Key	BS1995	27.1	4.7	25.9	28.3	26	6.2	24.4	27.6
	IOP	29.5	5.7	28.0	31.0	27.1	6.7	25.4	28.8
Butternu t Key	BS1995	28.3	4.8	27.1	29.5	23.3	9.9	20.8	25.8
	IOP	30.3	5.6	28.9	31.7	26.4	11.1	23.6	29.2

The only dry season average value confidence interval that does not overlap is the interval for Whipray Basin, though the end points of the intervals are the same. There is not much confidence interval overlap for the dry season for Little Madeira Bay, Terrapin Bay, and Duck Key at the 80% significance level. However, ISOP/IOP impacts at these three sites turned out to be significant at the 75% significance level. For the wet season, all of the average value confidence intervals overlap, meaning there is no statistically significant difference between BS1995 and ISOP/IOP runs.

To investigate further the potential of a dry season effect of ISOP/IOP operations (increased salinity), monthly average values were computed for each month over the 31-year simulation period. The results of monthly significance tests are summarized in Marshall (2003). For Joe Bay and Long Sound, there is no statistically significant difference for any month between BS1995 and ISOP/IOP runs at the 80% significance level. However, for the remaining six stations, the ISOP/IOP run monthly average salinity was significantly higher than the BS1995 salinity at the 80% level for most of the months in the dry season. For Little Madeira Bay and Terrapin Bay, the increase is significant at the 80% level for the all of the months of the dry season. At the North River station, the only station in this evaluation that receives direct flows from Shark Slough, the monthly average increases are significant (80% level) for the dry season months of October, November, December, and January. At Whipray Basin, the increases are significant (80% level) for all of the dry season months except January, and for the wet season months of July, September, and October. For Duck and Butternut Keys, the increase is significant (80% level) for the dry season months of January through May.

4.3 Conclusions

The study by Marshall (2003) demonstrates that statistical models based on a multivariate linear regression technique can be used for the reasonable simulation of daily salinity values. The IOP evaluation procedure uses the statistical models with SFWMM output for Everglades water levels and measured data for wind and tide to simulate long-term operations for BS1995 and IOP water delivery scenarios. These simulations do not represent actual operation conditions. However, this process is very useful for quantifying the additional effect of IOP implementation under the baseline hydrologic condition. Long-term simulation using SFWMM stages shows overall effectiveness as a means to estimate the changes of salinity introduced by IOP. The statistical modeling exercise and the hydrologic evaluations produced comparable results. The followings are major conclusions drawn from the result of this study:

There is a statistically significant dry season effect of IOP operations on the salinity regime (increased salinity) of the central near shore embayments of Florida Bay. The same is true at the downstream tidal reach of Shark Slough (North River), and at the open water stations in central and eastern Florida Bay. These conclusions are based on the results of statistical analysis for the monthly time frame based on 31-year simulations of the hydrologic system using SFWMM estimates for water levels in the Everglades and historical input for wind and sea level parameters. A statistically significant increase is also seen at two near shore stations (Little Madeira Bay and Terrapin Bay) and one open water station (Whipray Basin) during some of the months in the wet season.

These simulations are representative of the effect of either ISOP/IOP or ISOP operations. The results of ISOP/IOP runs show a negative impact at Little Madeira Bay, Terrapin Bay, North River, Whipray Basin, Duck Key, and Butternut Key, because high dry season salinity values can lead to hypersaline conditions, in general. On the other hand, the ISOP/IOP and ISOP operations appear to have created a situation in Joe Bay and perhaps Long Sound that is closer to the conditions simulated by the NSM run, according to this evaluation of average values over 31 years of simulation.

4.4 Recommendations for Further Research

Further in-depth research may be needed to identify the following questions:

- Why are water levels at upland stations (especially CP and P33) so important for predicting salinity in Florida Bay?
- Would models using water temperature at a salinity station provide a surrogate for evaporation potential and improve the models?
- Why was there minimal reaction in Joe Bay and Long Sound to IOP?
- Why were Little Madeira and Terrapin Bay significant parameters in the Whipray, Duck, and Butternut models and Joe Bay and Long Sound eliminated by the step-wise selection procedure?

This type of study should be extended to confirm the salinity impact on western side of Florida Bay. The current study covers only one location (North River), which may not be enough to draw a meaningful conclusion on that area. NSM salinity can also be compared to salinity produced using SFWMM runs for Modified Water Deliveries and C-111 projects to see if objectives are being reached. We need to begin investigating the effect of optimization of operations, maybe using the statistical salinity time series model that is very useful for the purpose of optimization.

5. Final Remarks

Salinity at most monitoring sites in Florida Bay and Gulf Coast estuaries increased during the ISOP/IOP period compared to the Test 7I period, which is not desirable for the health of the ecosystem in Florida Bay. The increase is not significant in most cases, but annual salinity at Canepatch on the Shark River March salinity at Canepatch and Broad River were significantly increased. Long term salinity simulations using multivariate regression models predicted higher salinity under ISOP/IOP than under without-ISOP/IOP at Little Madeira, Terrapin Bay, North River, Whipray Basin, Duck Key, and Butternutt Key, but they were lower at Joe Bay and Long Sound. However, the differences were not statistically significant. The result of long-term simulations is also consistent with the result of salinity BACI analysis in terms of increased salinity during the ISOP/IOP period at most sites compared to that during the Test 7I period.

6. Literature Cited

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